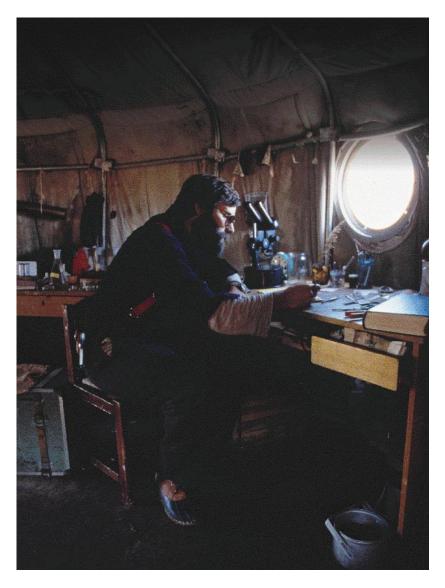
## Searching for Parasitic "Roots"



The Past Is
Key To
Understanding
the Present

It takes knowledge of taxonomy, host-parasite relationships, and geographic range—the science of systematics—to tell it like it really is.

According to the United Nations Global Biodiversity Assessment, the world fauna is estimated to include 10 to 100 million species; well in excess of 3 million are parasites. They have parasitized the world's vertebrates and invertebrates for millions of years and so make up a significant component of global biodiversity. Yet, probably less than a third have been described or named.

Large, disease-causing macroparasites such as tapeworms, flukes, and roundworms are a constant threat to economically important fisheries, livestock, wildlife—and to people.

But while parasites inflict a high economic cost, they also serve as "elegant indicators of the present-day ecology and geographic distributions of their hosts," says Agricultural Research Service zoologist Eric P. Hoberg. He is one of just a handful of U.S. systematic parasitologists who look at parasite geographical distribution and coevolution. He says that each parasite species, because of its predictable life history, can be used to examine ecological factors of its hosts.

"Besides telling us something about their hosts' diet, behavior, and habitat, parasites can tell us about their geographical connections of long ago," he says. "They are the products of both a current environment and, at the same time, of a long ancestry reflecting millions of years of host association."

## It Takes a Special Scientist

The task of discovering and scientifically describing living organisms is the responsibility of a highly specialized group of scientists who, like Hoberg, are trained systematists.

They integrate the standardized naming of organisms (nomenclature) with understanding of evolutionary relationships among species (phylogeny), to ultimately classify organisms into hierarchical groups (taxonomy).

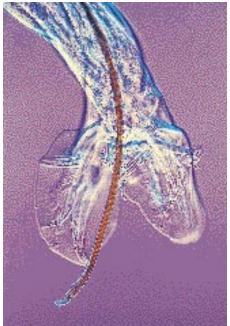
As taxonomists, systematists carefully examine living species and officially describe them by detailing their distinguishing characteristics in very exacting terms—morphological (form and structure), biochemical, and molecular. Without the expertise of systematists, the millions of species of organisms remaining to be described—insects, fungi, bacteria, nematodes, plants—cannot be recognized and classified.

"These classifications represent everything we know about the relationships among organisms," says Hoberg. "Even more important, they help predict species behavior. In a sense, if we know which order, family, or genus a parasite belongs to, we can then predict with some certainty what effect it will have on hosts in the same or related families."

Field studies have taken ARS zoologist Eric Hoberg across North America, Siberia, and Antarctica. At a camp on Talan Island in Chukhotka, Russia, he sorts specimens that will eventually be used in supporting his Arctic refugium hypothesis of host and parasite species development. Hoberg works at the Beltsville (Maryland) Agricultural Research Center, in the ARS Biosystematics and National Parasite Collection Unit that has historically concentrated on parasites of food animals.

He is an expert in biodiversity, cospeciation (evolutionary associations between parasites and hosts), and biogeographic analysis (study of the geographic distribution of living

ERIC HOBERG



Systematists identify a male *Nematodirus* spathiger nematode by studying its tail and copulatory structures (magnified about 130x).

things). He has studied the systematics and evolution of tapeworms of seabirds and of pinnipeds such as seals and sea lions, as well as the roundworms of ruminants.

"Parasites have characteristic host and geographic distributions and predictable life cycles and transmission patterns," says Hoberg.

He is associate curator of the USDA-ARS U.S. National Parasite Collection. His research has earned him the H.B. Ward Medal from the American Society of Parasitologists.

In 1994, ARS recognized him as Outstanding Early-Career Scientist for his creative studies of systematics, cospeciation, and biogeography of parasites in wild and domestic vertebrate hosts.

Hoberg and a small staff of ARS parasitologists curate the collection, identifying and naming all types of parasites of vertebrates—nematodes (roundworms), flukes, and tapeworms—including avian and mammalian hosts.

Theirs is one of the world's largest collections, with about 95,000 lots representing several million specimens. About 1,000 new groups of specimens are added annually to the collection. In recent years, Hoberg has named 20 new species, 4 genera, a family, and an order of parasites, based on research he did alone and with colleagues.

## **Building a Unifying Framework**

Hoberg uses this vast collection and his knowledge of parasite systematics to examine evolutionary relationships between hosts and parasites. This research, called cospeciation analysis, includes studies of contemporary and historical biogeography, or distribution—that is, where hosts and parasites now occur and where they originated.

As a result of his work on tapeworms of seabirds and pinnipeds, he formulated the "Arctic Refugium" hypothesis that recognizes the role of global climatic fluctuations and habitat distributions during ice ages as determinants of the process by which host and parasite species are formed. It postulates that islands of habitat suitable for occupation by animals existed in northern regions during the ice ages. And in these islands, or refugia, isolation of small populations of hosts and parasites resulted in the origin of species.

This hypothesis has provided scientists with a unifying framework for

understanding the history of marine fauna in the North Pacific basin and Holarctic region (northern North America, Siberia, and Europe) over the past 3 million years.

Concepts derived from these studies are now being used to comprehensively evaluate the biogeography and evolutionary history of trichostrongyle (stomach and intestinal) nematodes of cattle, sheep, deer, and related ruminants across the northern hemisphere.

"Most parasite systematists concentrate only on the parasites, and most vertebrate systematists focus only on free-living groups like birds, fish, or mammals," Hoberg says. "An integration of parasitology and vertebrate biology, however, can give us considerably more information.

"Knowledge of parasites applied to questions of biodiversity can, for example, tell us about historical or contemporary associations, what hosts eat, and where they forage and spend time, along with information on seasonal migratory paths.

"It is also important to survey and inventory parasites in order to document biodiversity, so we can understand what parasites typically occur in a region. Then we can recognize the introduction of potentially pathogenic, or disease-causing species."

For example, intercontinental movement of hosts such as ruminants (cud-chewing grazing animals) and ratite birds (ostriches, emus, and rheas), accompanied by introduction, establishment, and emergence of exotic parasites, is a continuing problem throughout the world.

"In the United States, we have recently discovered a new species of pathogenic nematode that is potentially fatal to ostriches. And we have identified numerous exotic nematodes from wild antelopes imported from Africa," says Hoberg.

This ongoing pattern of introduction of hosts and parasites highlights



The precise description of each species is the cornerstone of the science of systematics. Here, zoologist Eric Hoberg makes detailed drawings of a previously unknown tapeworm. (K7505-1)

the need to do exhaustive research in systematics of nematodes in domestic and wild hosts across Eurasia and Africa. Historically, North American and Eurasian faunas were linked by the Bering land bridge, connecting Alaska and Siberia. That established a phylogenetic and biogeographic link between the host and parasite faunas of the Old and New Worlds that has been significant for evolution of trichostrongyle nematodes of ruminants over the past 20 million years.

Broad-based studies of these parasites are necessary to understand the species diversity and structure of the parasite fauna of both domestic and wild ruminants, which is a mosaic of ancient and recently introduced species. Hoberg believes that systematics provides the foundation for understanding the history and biogeography of such host-parasite relationships and for predicting parasite behavior when helminths are introduced to new hosts or ecological settings.

Recently, Hoberg studied the history of emergence of two serious parasites—of sheep and of muskoxen—that could have serious implications.

*Nematodirus battus* is widely regarded as the most pathogenic parasite in lambs in the Northern Hemisphere. Although the modern history of *N*.

battus is strongly tied to domesticated sheep, its ancestral host group has remained a mystery.

Though it was probably inadvertently brought into the United States in the early 1980's, Hoberg discovered *N. battus* in Oregon in 1984. A 1986 survey by the USDA's Animal and Plant Health Inspection Service showed that it had already become established on both coasts.

"Pathogenicity of this parasite is attributable to large numbers of developing larvae that are ingested from pastures while sheep forage," says Hoberg. "In England, farmers may lose up to a third of their lambs because of this nematode."

Anthelmintic drugs now help to prevent infestations. And local forecasting predicts the seasonal emergence of parasite larvae, enabling farmers to limit exposure of lambs.

It appears that international transport of infected domestic sheep spread the parasite across parts of the Northern Hemisphere.

Hoberg and colleague Steven Nadler at the University of California, Davis, conducted phylogenetic analyses of molecular data that support a history of its recent introduction from the United Kingdom to Canada and the United States.

Systematics was also used to illuminate the historical host range of this and related parasites. Hoberg studied and analyzed the evolutionary relationships among 11 species of *Nematodirus* from ruminants, including *N. battus*. This species was found to be closely related to species of *Nematodirus* from deer—rather than to those species that occur among sheep and goats.

"This suggests that a host-switch or colonization from deer resulted in the occurrence of *N. battus* in sheep," says Hoberg. "And it tells us that the parasite is not host-specific, limited to a particular phylogenetically related group of hosts. Instead, it is a po-

tential problem to all domestic and wild grazing animals, now that it is present in North America."

Hoberg says there is a nematode of muskoxen in the Canadian Arctic that is still an enigma with respect to its origins, contemporary host range, and biogeography.

Umingmakstrongylus pallikuukensis, recently named by Hoberg and a Canadian research group, is the largest known lungworm. Females are over a foot and a half long, and males and females live in massive nodules in the lungs of muskoxen. Infected muskoxen defecate larvae that infect and develop in slugs and perhaps other mollusks that are likely ingested by grazing animals foraging in meadows.

The lungworm, discovered in 1988 by Canadian biologists, apparently causes sickness and possibly death in heavily infected animals and reduces their overall vitality. Hoberg, along with Lydden Polley from the University of Saskatchewan and Anne Gunn and John Nishi from the government of the Northwest Territories, described the lungworm's morphological features and presented hypotheses for its biology and biogeography in the Arctic.

Hoberg believes that *U. pallik-uukensis* may have implications for managing wild ruminants in the Arctic, since a major management practice for muskoxen involves the reintroduction of animals to areas where these arctic ruminants were hunted to local extinction in the last century.

"Such translocation could lead to the introduction of parasites, along with their hosts, or expose parasitefree animals to infection," he says.

Hoberg's studies also show that *U. pallikuukensis* is not an exotic parasite but is apparently endemic to the Arctic. However, the exceptionally high prevalence of infection—near 90 percent in some areas—and its ability to cause disease suggest it has recently emerged.



The typical shape and color of eggs of the disease-causing *Nematodirus battus* nematode, shown in the uterus of a female worm (magnified about 130x), help identify the species.

"This parasite may have an adverse impact on food resources, such as muskoxen, which are a traditional food source for native cultures in the Arctic," he says. A multidisciplinary team of scientists that includes Hoberg and other parasitologists and vertebrate biologists is working to unravel the coevolutionary history of this host and parasite.

Hoberg's research shows that parasites are of more than just intrinsic in-

terest because of their economic impact on ruminant animals. It also makes it clear that these obscure organisms tell us stories about the intricate and complex history of hosts and geographic regions.

Hoberg believes that knowing the past is the key to understanding the present. "Historical studies involving parasites contribute to a predictive foundation for understanding biotic communities and environments," he says. "These studies lead to substantial progress in developing new diagnostic methods and assessments of biogeography and host range of economically significant parasites and their allies.

"Parasites are powerful tools, or keystones, for addressing questions of the origin, maintenance, and distribution of biodiversity."—By **Hank Becker**, ARS.

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The muskox may be the sole host for the largest known lungworm, *Umingmakstrongylus pallikuukensi*. This parasite infects up to 90 percent of the muskoxen in a region near the lower Coppermine River in Arctic Canada.